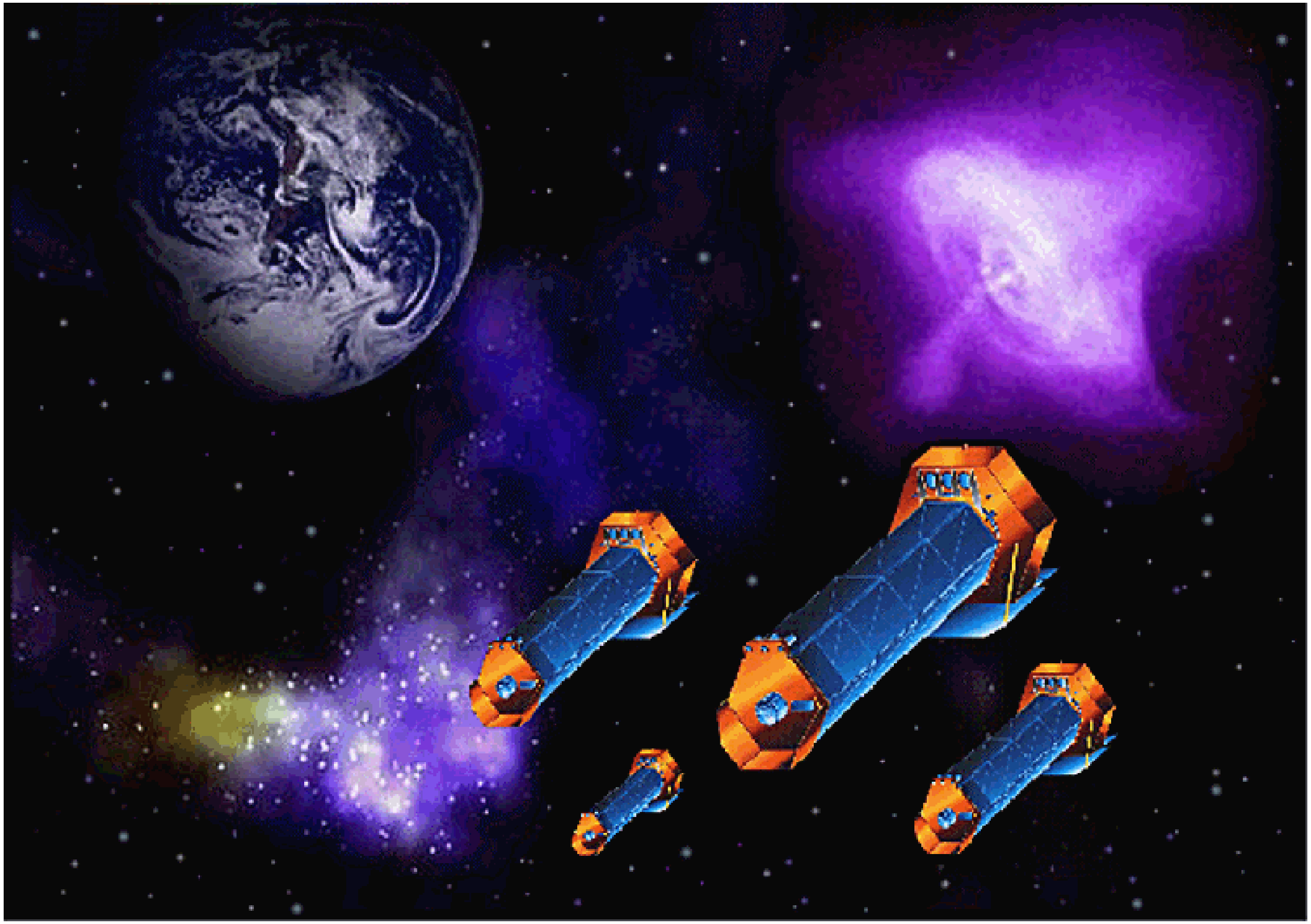
The Constellation X-ray Mission



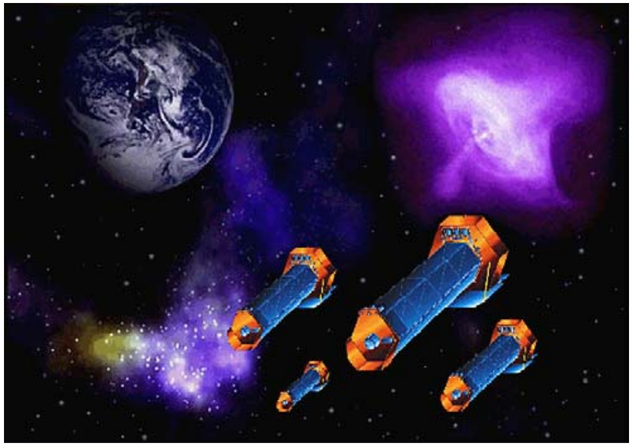
Nicholas White (GSFC)

On behalf of the Constellation-X team

http://constellation.gsfc.nasa.gov

Constellation-X Mission Overview

Use X-ray spectroscopy to observe



- **Black holes: strong gravity & evolution**
- **Large scale structure in the Universe**
- **Production and recycling of the elements**

Mission parameters

- **Telescope area:** 3 m^2 at 1 keV
  25-100 times XMM/Chandra for high resolution spectroscopy
- **Spectral resolving power:** 300-3,000
  5 times improvement at 6 keV
- **Band pass:** 0.25 to 40 keV
  100 times more sensitive at 40 keV

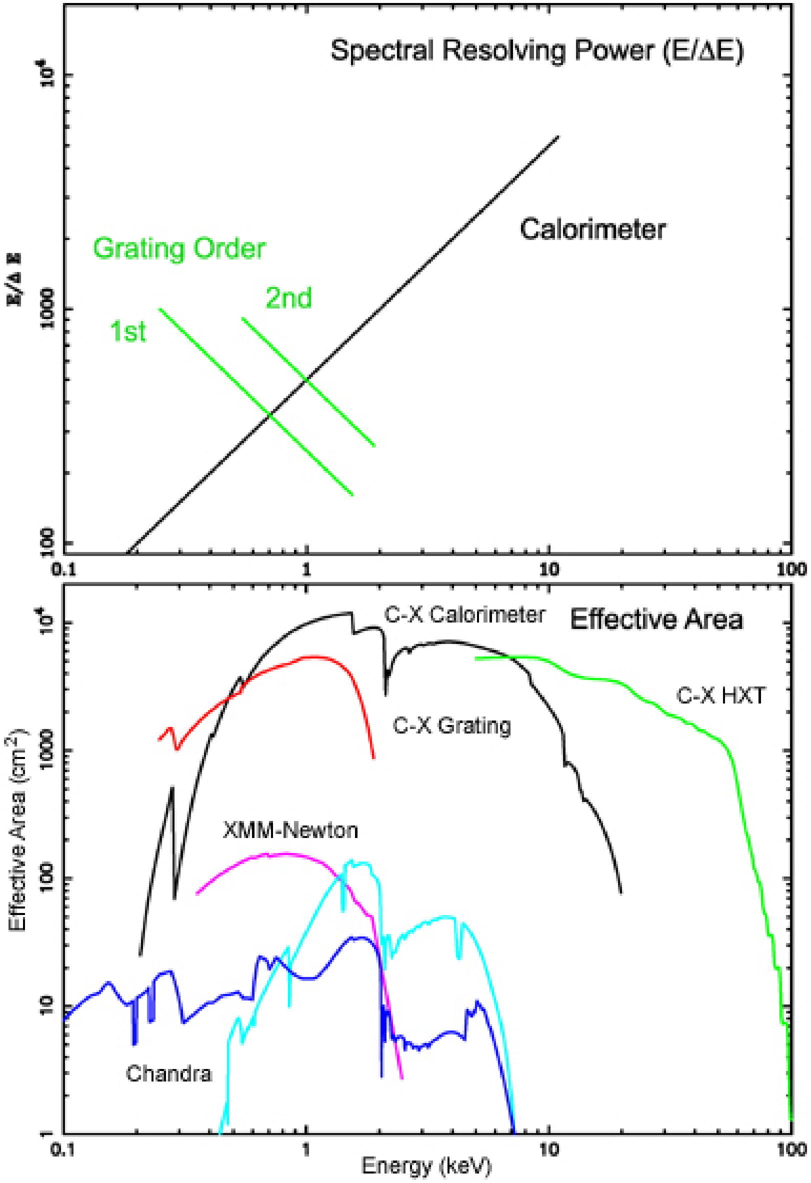
An X-ray Keck Observatory

An X-ray VLT

Enable high resolution spectroscopy of faint X-ray source populations

Constellation-X Mission Performance

Two coaligned telescope systems cover the 0.25 to 40 keV band



SXT: Spectroscopy X-ray Telescope

- 0.25 to 10 keV
- 15,000 sq cm at 1 keV
- 6,000 sq cm at 6 keV
- Resolution of 300-3000 with
  - ➔ 2eV microcalorimeter array
  - ➔ reflection grating/CCD
- 5-15 arc sec HPD angular resolution
  - ➔ 5 arc sec pixels, 2.5 arc min FOV

HXT: Hard X-ray Telescope

- 10 to 60 keV
- 1,500 sq cm at 40 keV
- energy resolution < 1 keV
- 30-60 arc sec HPD angular resolution

Overall factor of 20-100 increased sensitivity

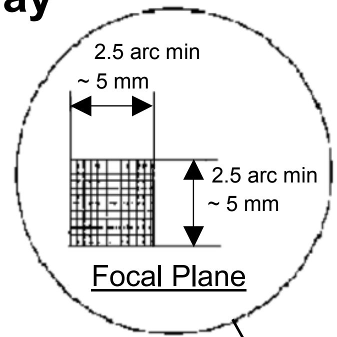
- gives ~ 1000 counts in 10^5 s for a flux of 2×10^{-15} ergs cm^{-2} s^{-1} (0.1 to 2.0 keV)

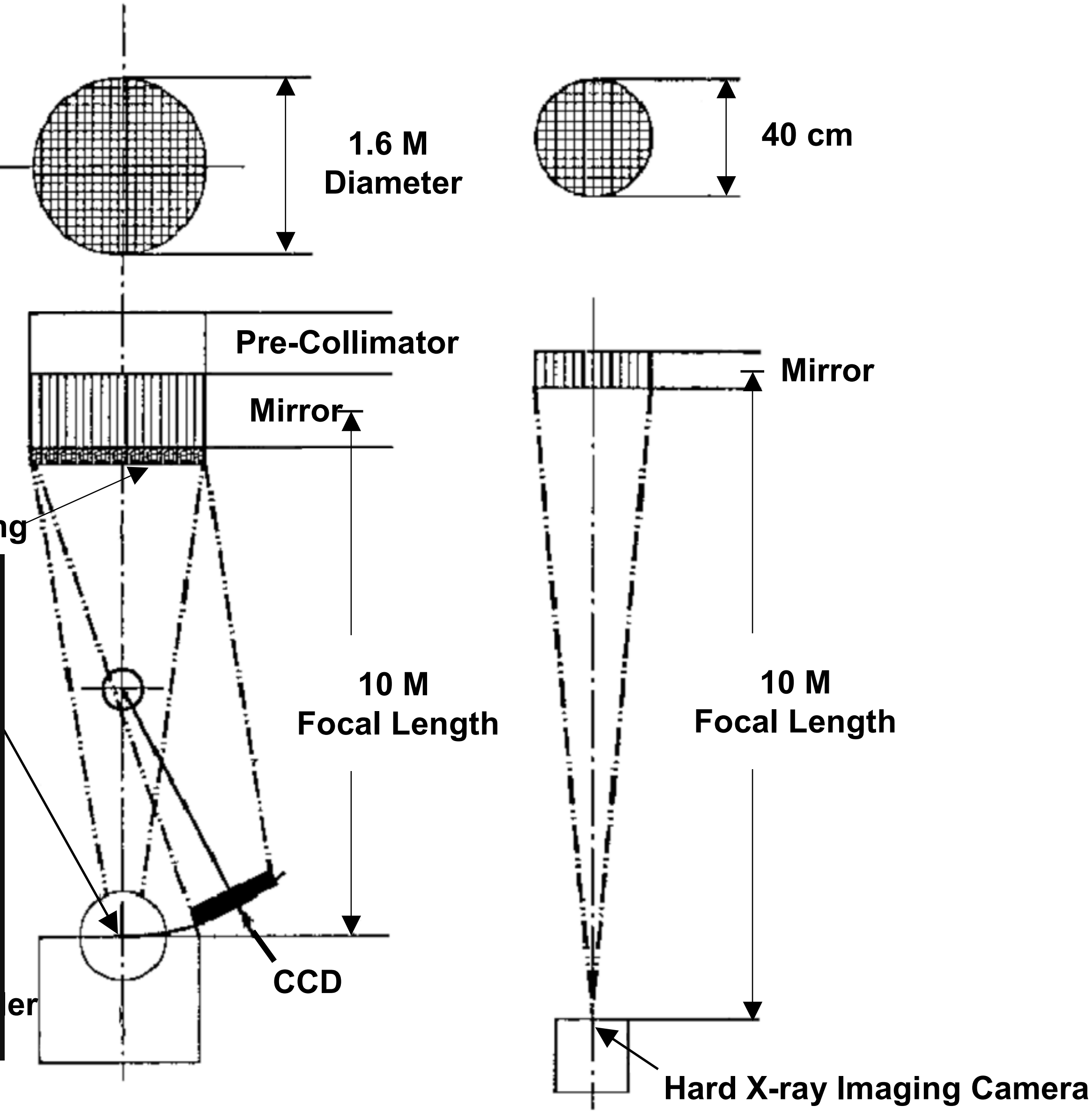
Constellation-X Instrumentation

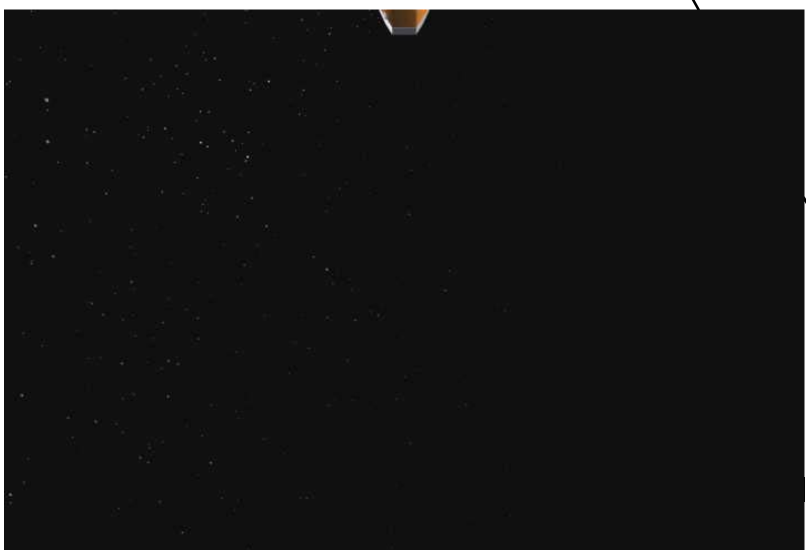
Spectroscopy X-ray Telescope   Hard X-ray Telescope

Calorimeter Array

- ~ 5 arc sec pixels
- 30x30 (900) pixels
- 2.5 arc min FOV





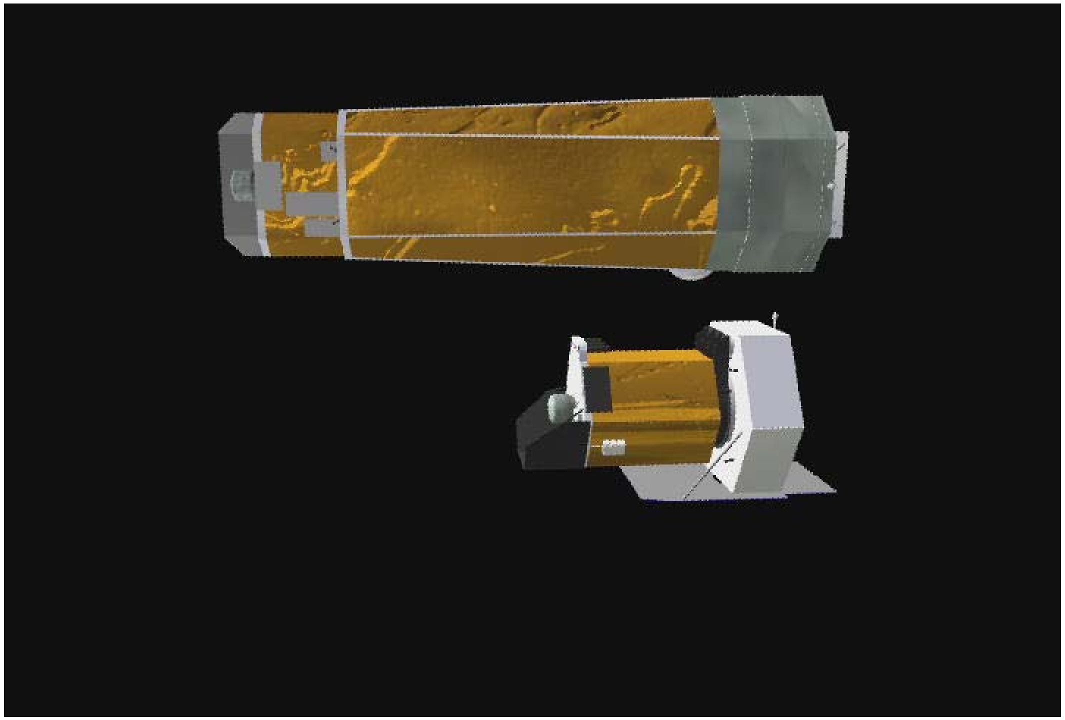


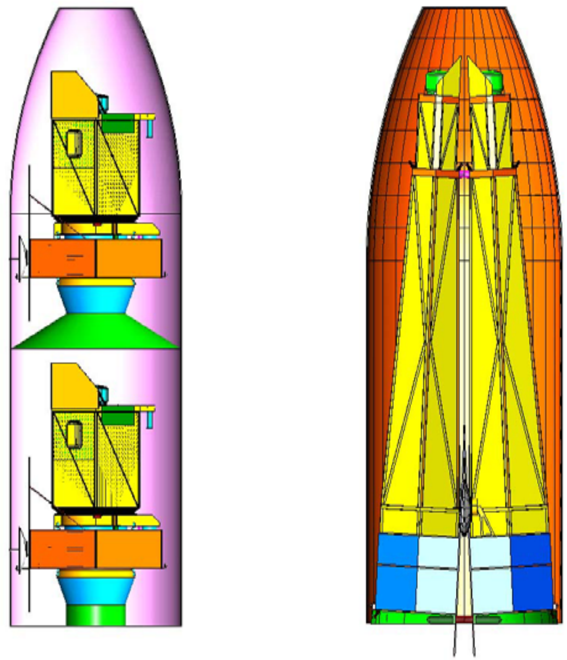
Constellation-X: A New Mission Paradigm

A Constellation approach:

– Four identical satellites, launched two at a time on Atlas V or Delta IV
– Modular design allows parallel spacecraft & instrument development & integration
– Cost effective standard spacecraft bus architecture and components
– Low risk and enables incremental improvements

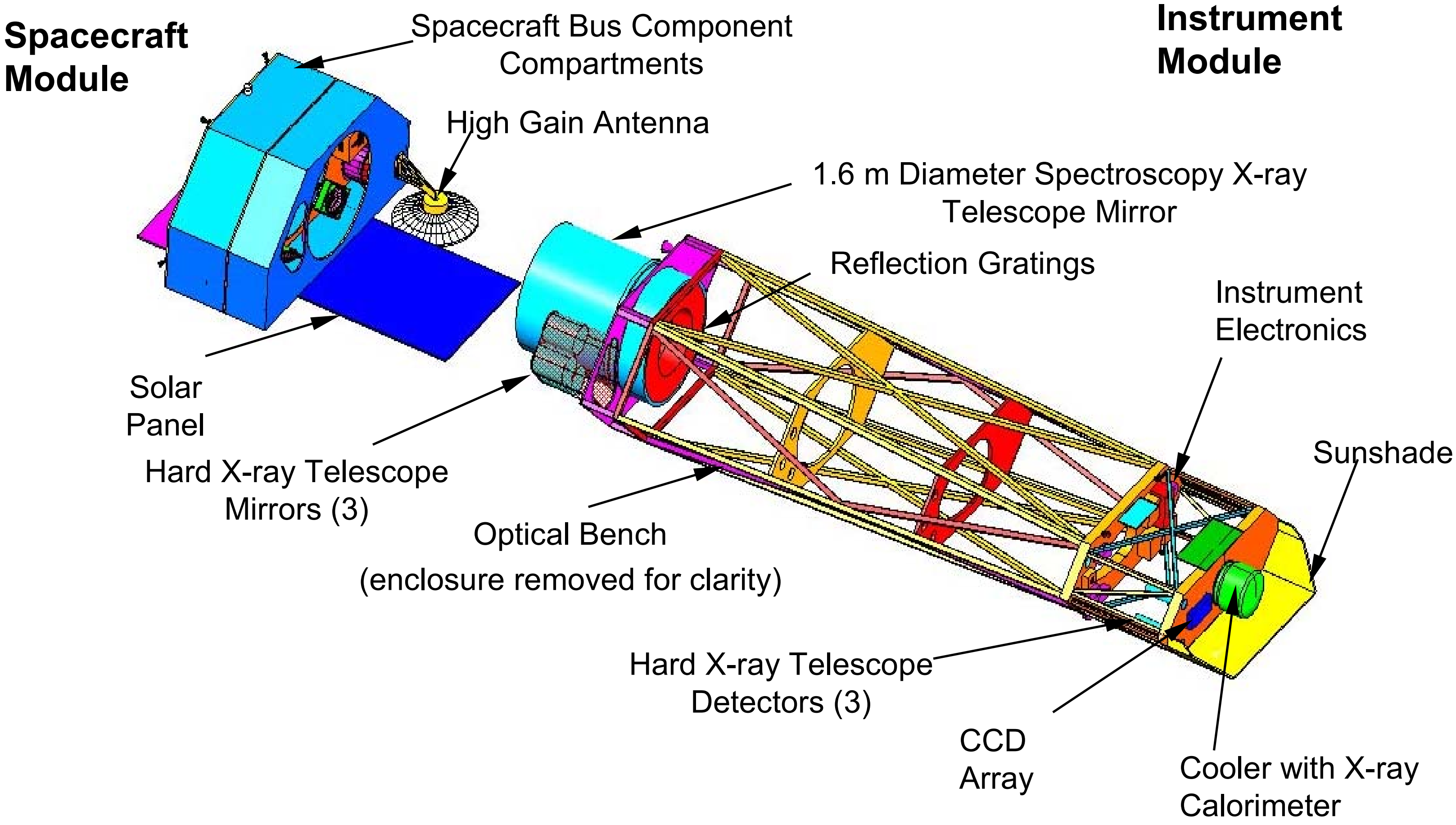
Extendible or fixed optical bench provides a focal length of 10 m



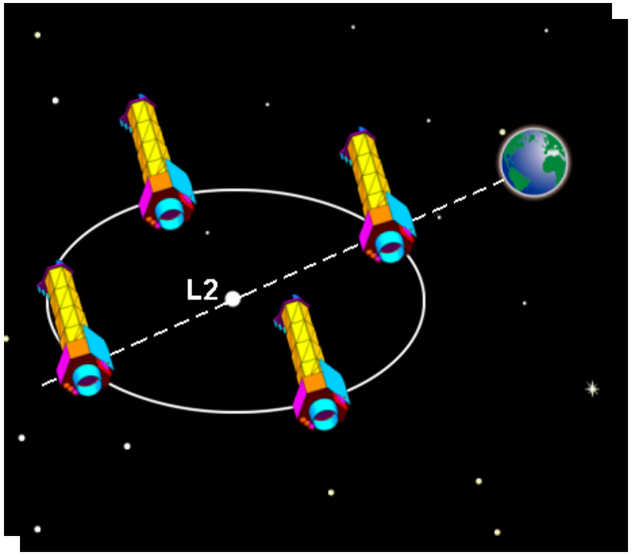


Alternate Launch Configurations

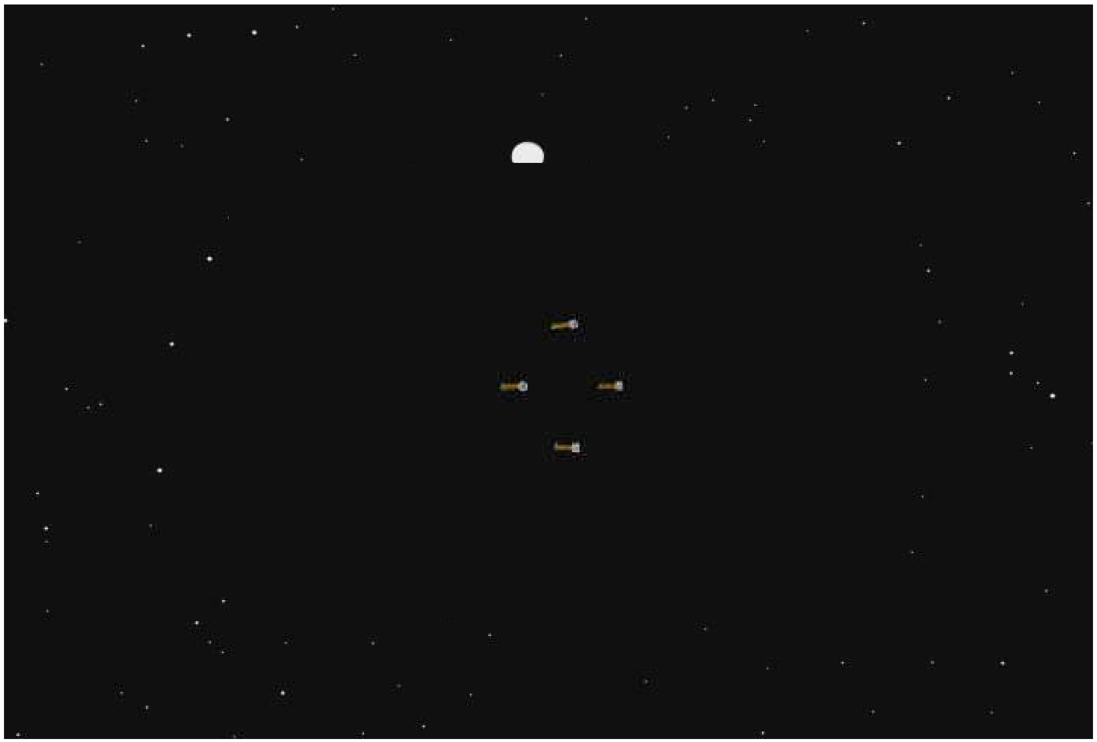
Constellation-X Fixed Bench Option



The Constellation-X Orbit



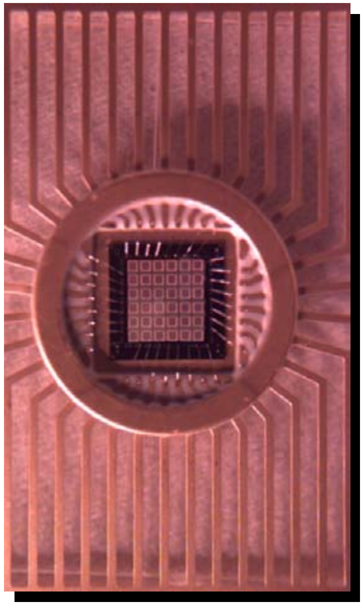
Deep space 2nd Lagrangian point (L2) orbit selected to give:
- High observing efficiency
- Simultaneous viewing
- Optimum thermal environment
- Simpler, lower cost spacecraft design



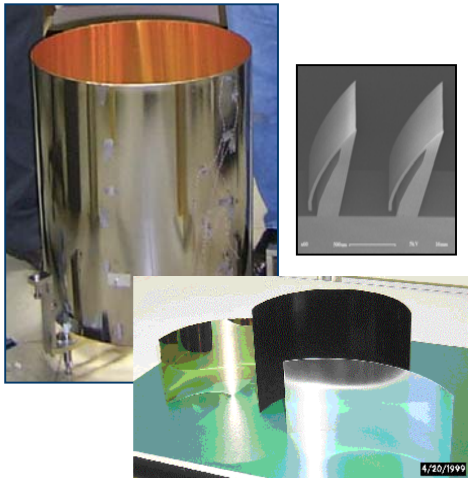
Lunar "swing-by" used to give maximum mass to orbit

130 day transit time (observations possible along the way)

Constellation-X Technology Requirements

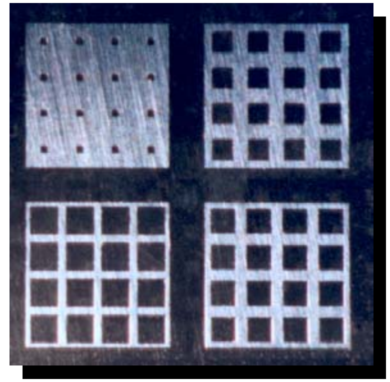


Microcalorimeters

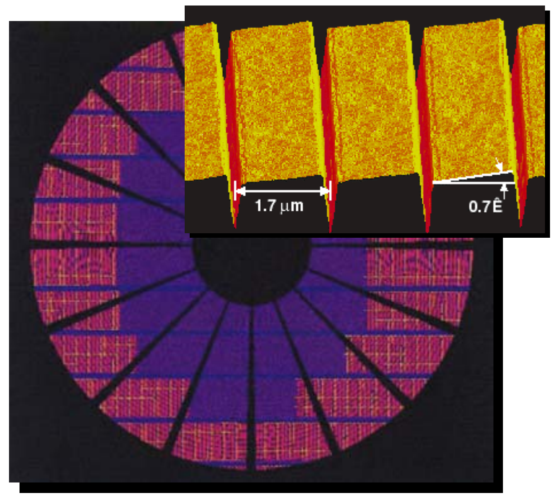


Lightweight
X-ray Optics

Multilayer Coatings

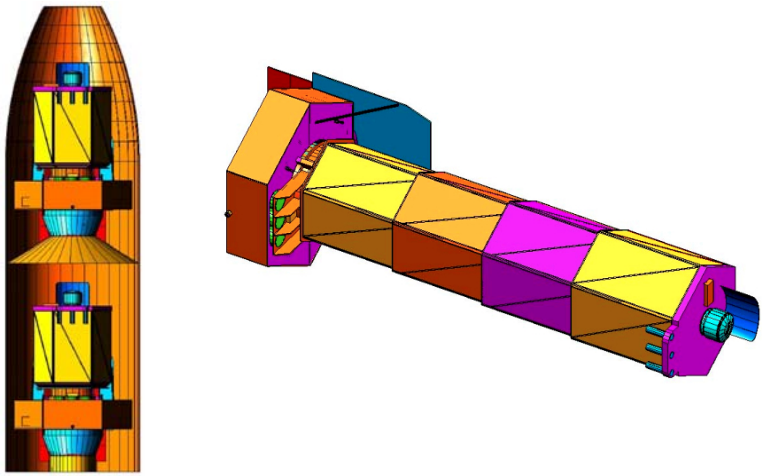


Hard X-ray Camera



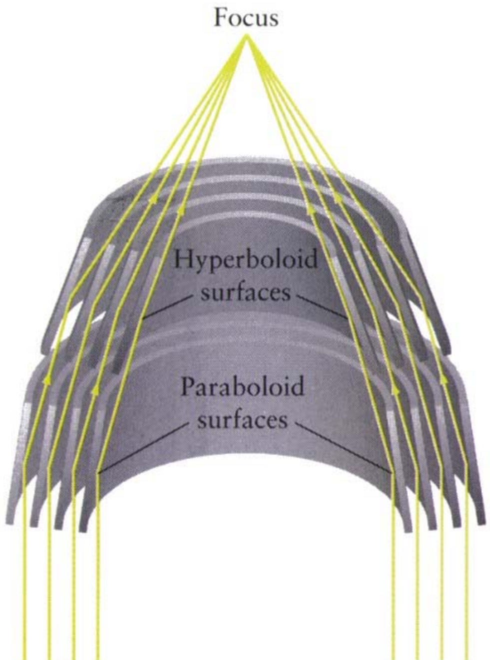
CCD/Grating

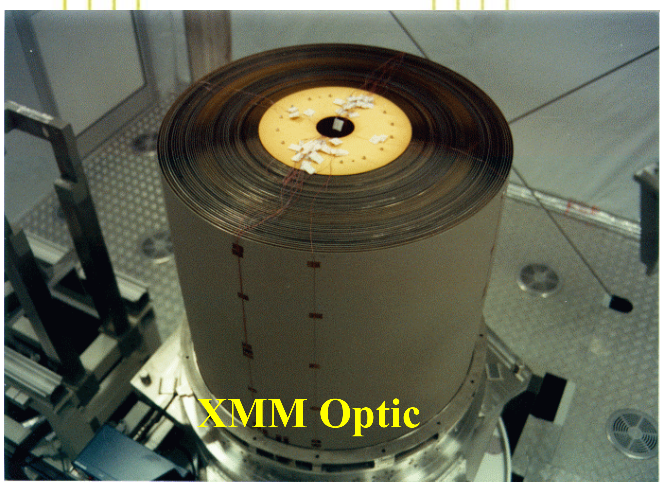
Coolers



Deployable Structures

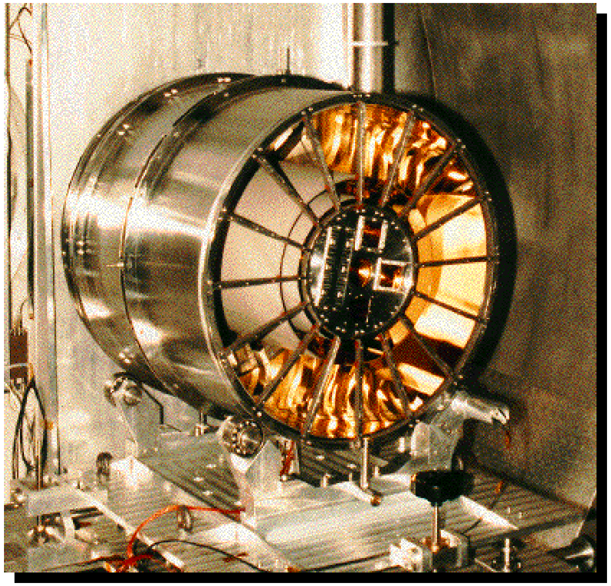
X-ray Optics Challenge





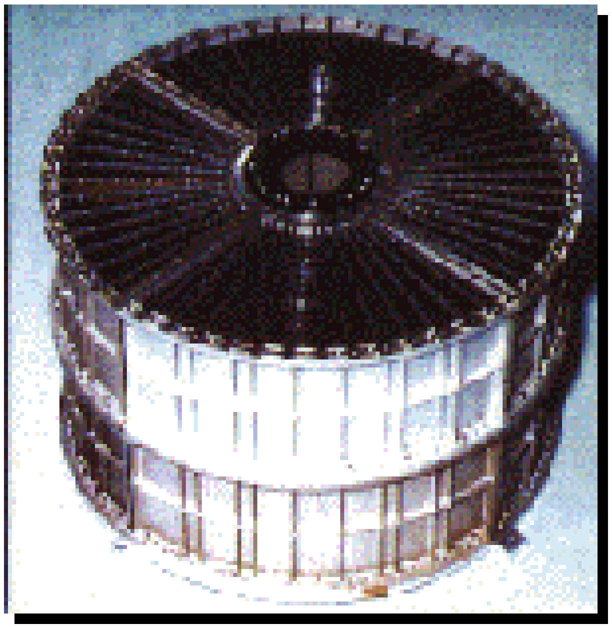
- X-ray optics work at grazing incidence
  - 300-700 more telescope surface area for a given aperture
  - Precisely figured hyperboloid/paraboloid surfaces
  - **Trade-off between collecting area and precision**
- State of the art is defined by Chandra
  - 0.5 arc sec resolution is ~100 times short of diffraction limit
  - Very expensive and heavy
  - **Polished surface area equal to a 5 m optical telescope!**
- Constellation-X will give 100 times increase in collecting area
  - Replicated shells or segments 0.5 kg/m^2 areal density
  - 5-15 arc second optics
  - **Polished surface area equals a 35 m optical telescope!**

SXT X-ray Mirror Design Alternatives



Replicated full-shell optics (e.g., XMM)

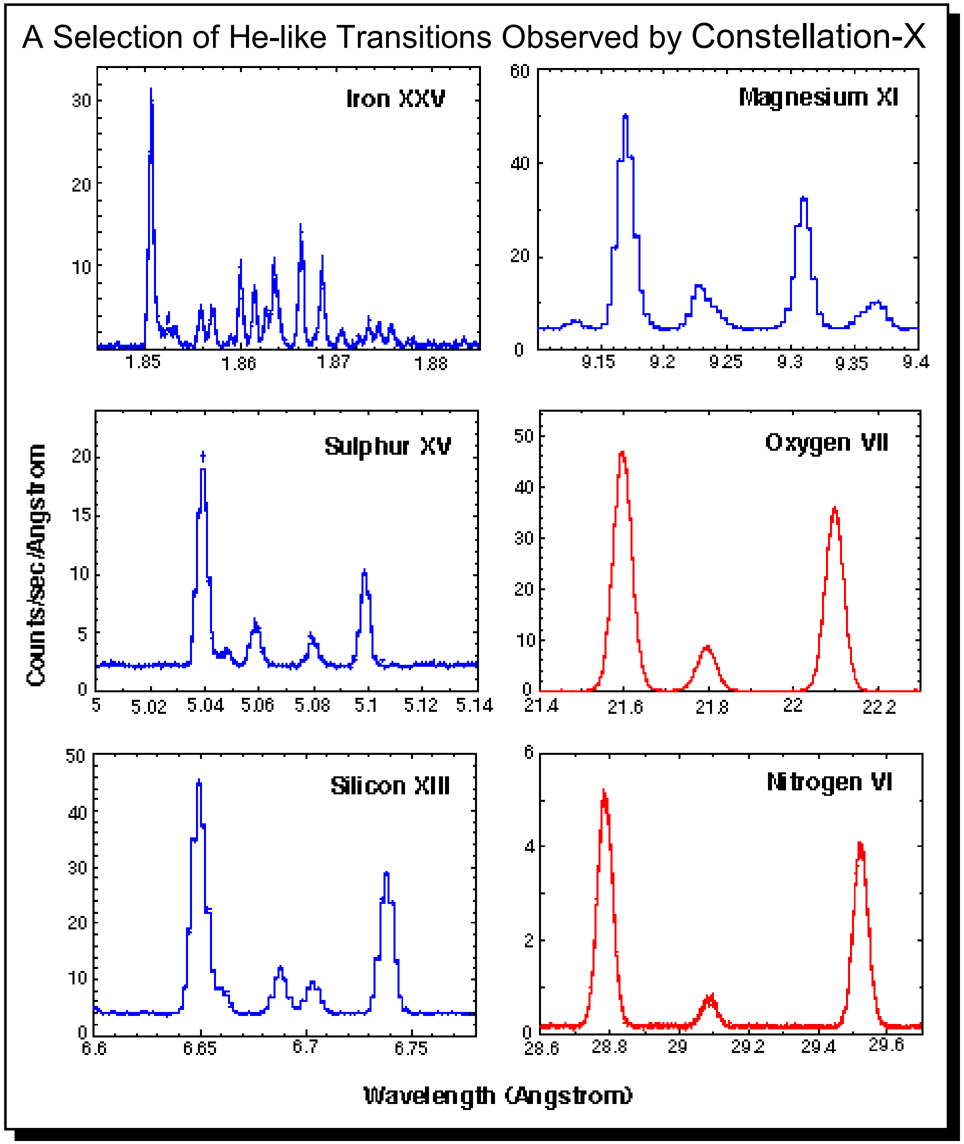
- meets 15-arcsec HPD requirement
- requires factor-of-six weight reduction
- investigating fiber-reinforced plastics and SiC and other ceramics as carriers for non-integral optics
- develop structurally reinforced, thin-walled, plated nickel alloys for integral optics



Replicated segmented optics (e.g., Astro-E)

- meets weight requirement
- requires factor-of-7 HPD improvement
- investigating stiffer substrates (metal matrix, composites, glass, Be, Aluminum, etc.)
- develop improved mandrels and foil-alignment techniques

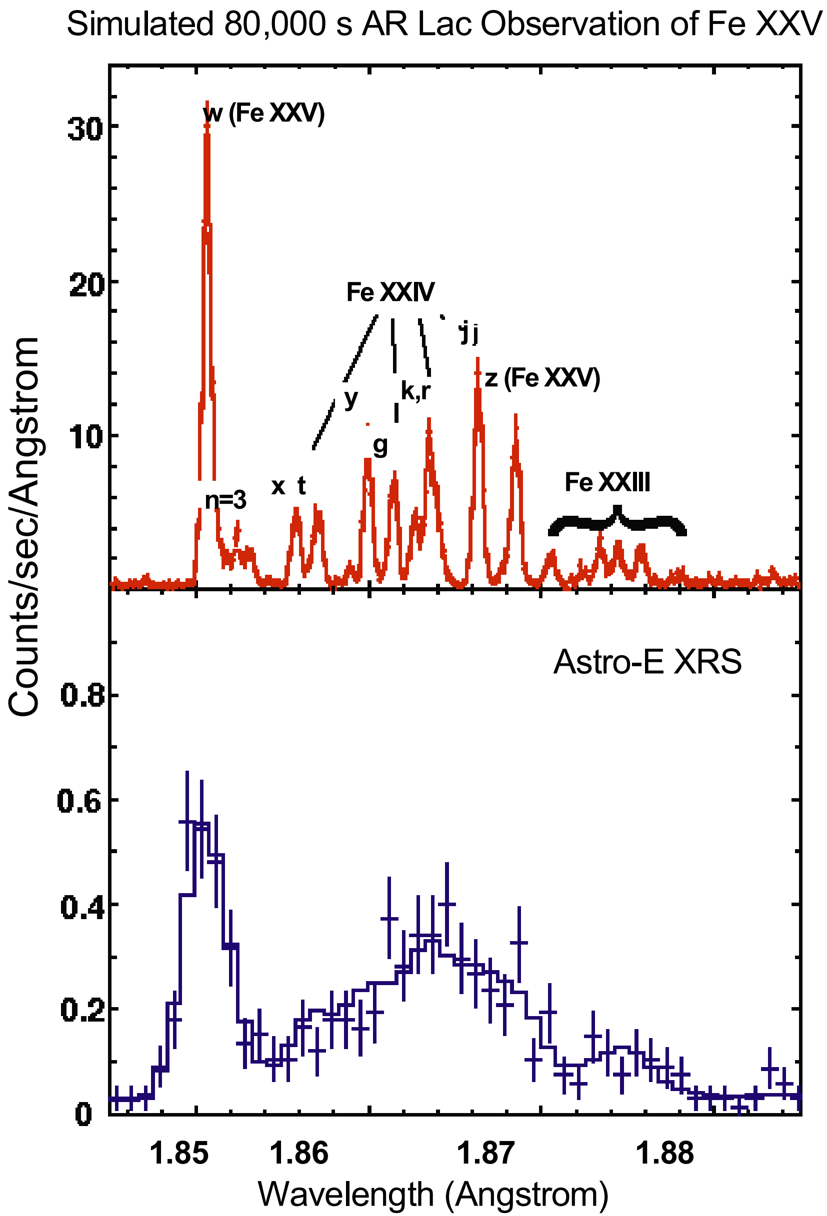
Plasma Diagnostics with Constellation-X



The Constellation-X energy band contains the K-line transitions of 25 elements allowing simultaneous direct abundance determinations using line-to-continuum ratios

The spectral resolution of Constellation-X is tuned to study the He-like density sensitive transitions of Carbon through Zinc

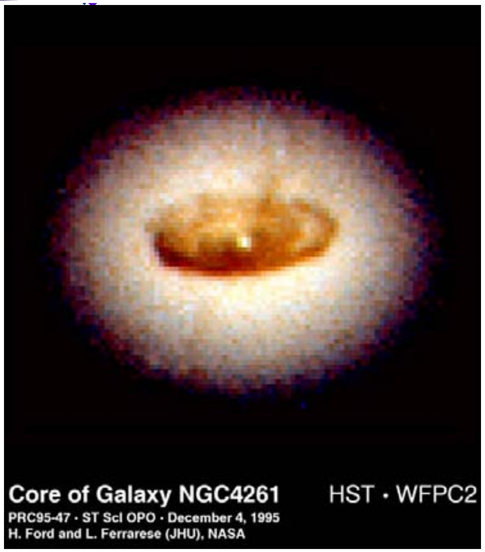
Constellation-X Micro-calorimeter Array

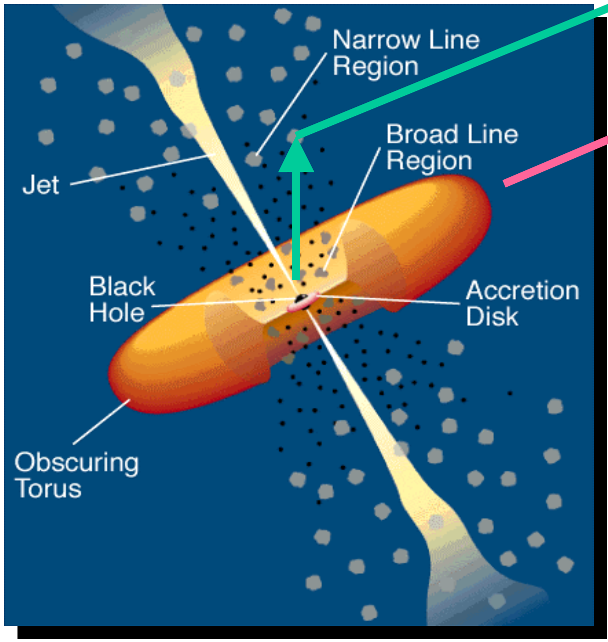


High quantum efficiency with the capability to map extended sources

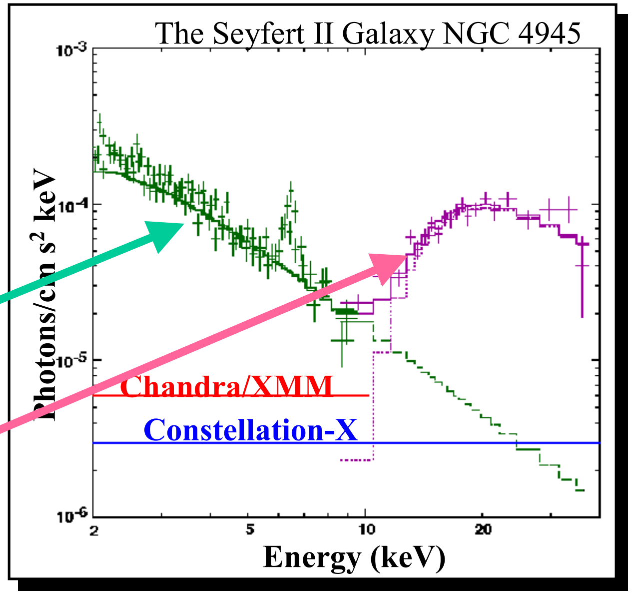
- A factor of 5 improvement (2 eV) in spectral resolution with R ~ 3000-4000 in iron K band (compared to ~10 eV for XRS)
- At Iron K, 2 eV resolution gives a bulk velocity of 100 km/s & line energy centroiding capability equivalent to an absolute velocity of 10 km/s
- $\geq 2.5 \times 2.5$ arc min field of view with 30 x 30 pixels (vs 6 x 6 for XRS)
- Ability to handle 1,000 ct/sec/pixel

Hard X-ray Response





Many black holes may be hidden behind an inner torus or thick disk of material



Only visible above 10 keV where current missions have poor sensitivity

Constellation-X will use multi-layer coatings on focusing optics to increase sensitivity at 40 keV by >100 over Rossi XTE

Roadmap to Image a Black Hole

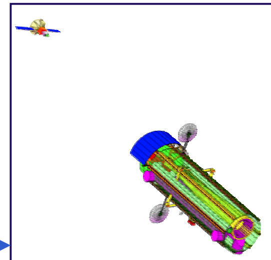
Imaging

Chandra

0.5 arc sec

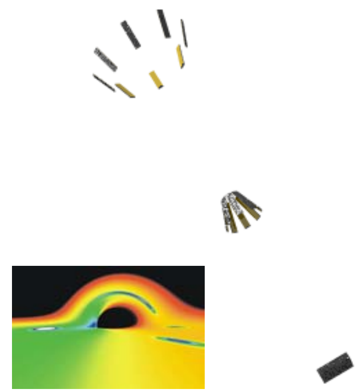
Optimize MAXIM Parameters

1000 times finer imaging



MAXIM Pathfinder

10 Million times finer imaging

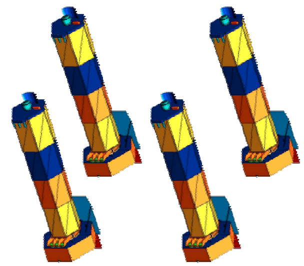


MAXIM

Spectroscopy

XMM

Constellation-X



100 times larger area

Find them

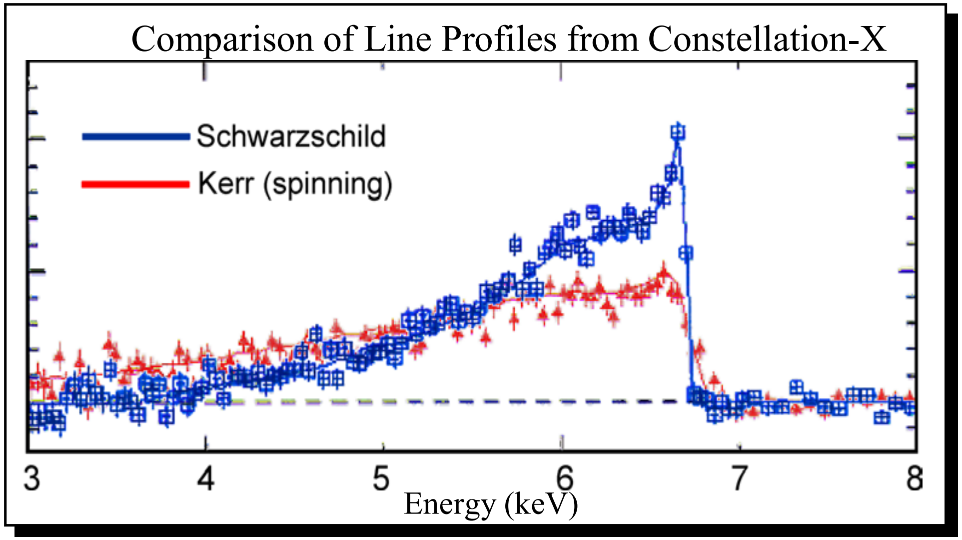
Conditions in the inner disk

X-ray interferometry first flight

Black hole imager!

2000 *2008* *2014* *2020*

Constellation-X Observations of Inner Region Near Black Hole Event Horizon



Constellation-X will determine black hole mass and spin using iron K-α lines

- **Spin from the line profiles**
- **Mass from the time-linked intensity changes of line and continuum**

QuickTime™ and a
GIF decompressor
are needed to see this picture.

QuickTime™ and a
GIF decompressor
are needed to see this picture.

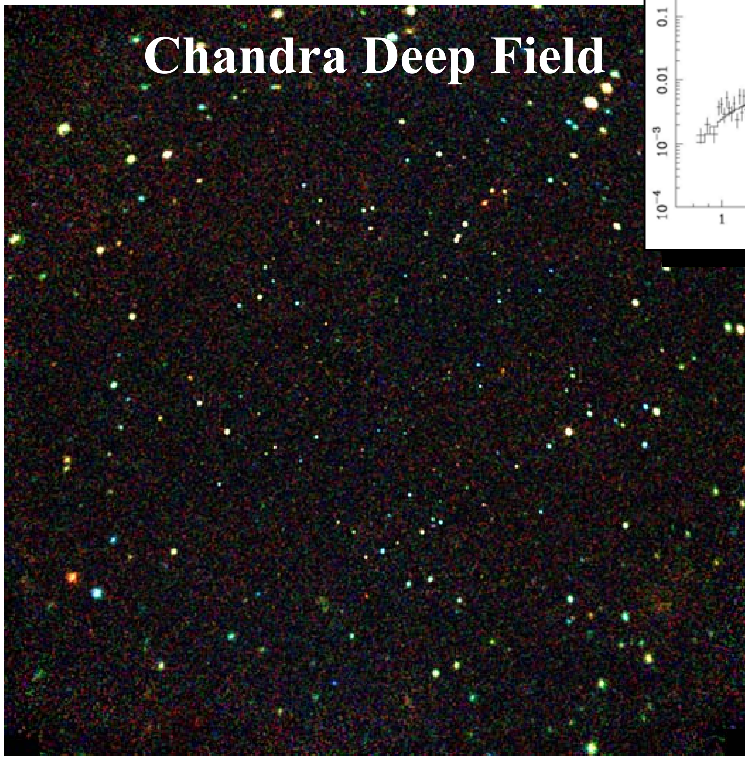
Reconstruct “images” of inner disk via deconvolution of the line profile

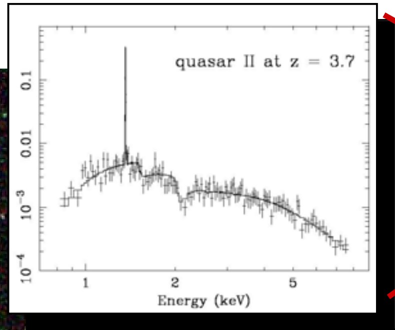
Observer the effects of strong gravity

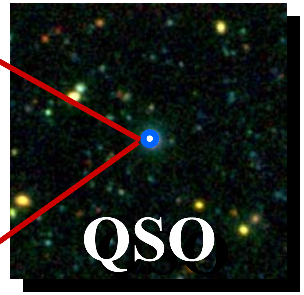
Credit: Paul Nandra & Chris Reynolds

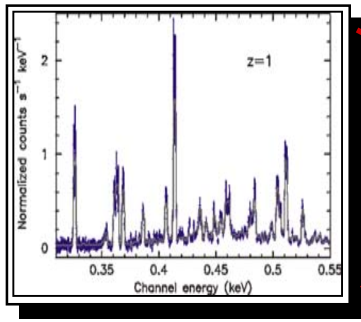
Chandra Finds Black Holes Are Everywhere!

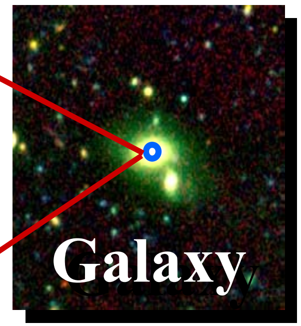
Chandra deep field has revealed what may be some of the most distant objects ever observed

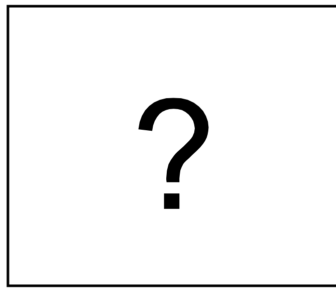


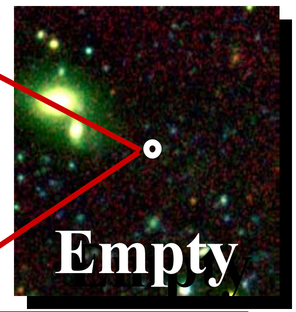








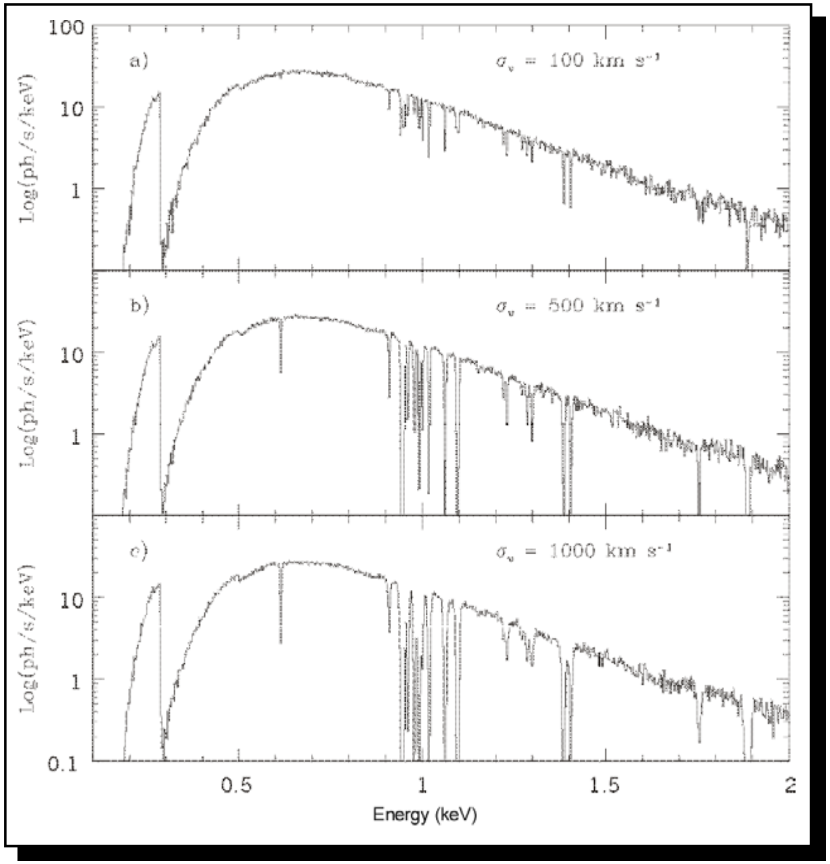




Credits: Giacconi, Garmire, Mushotzky

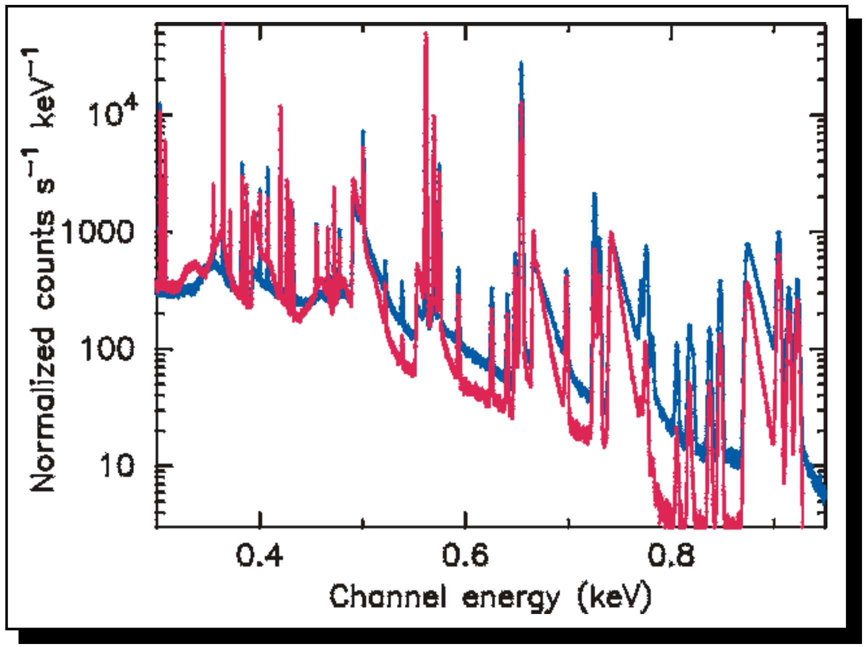
Constellation-X will obtain high resolution spectra of these faint X-ray sources to determine redshift, source conditions & black hole evolution

The AGN Environment



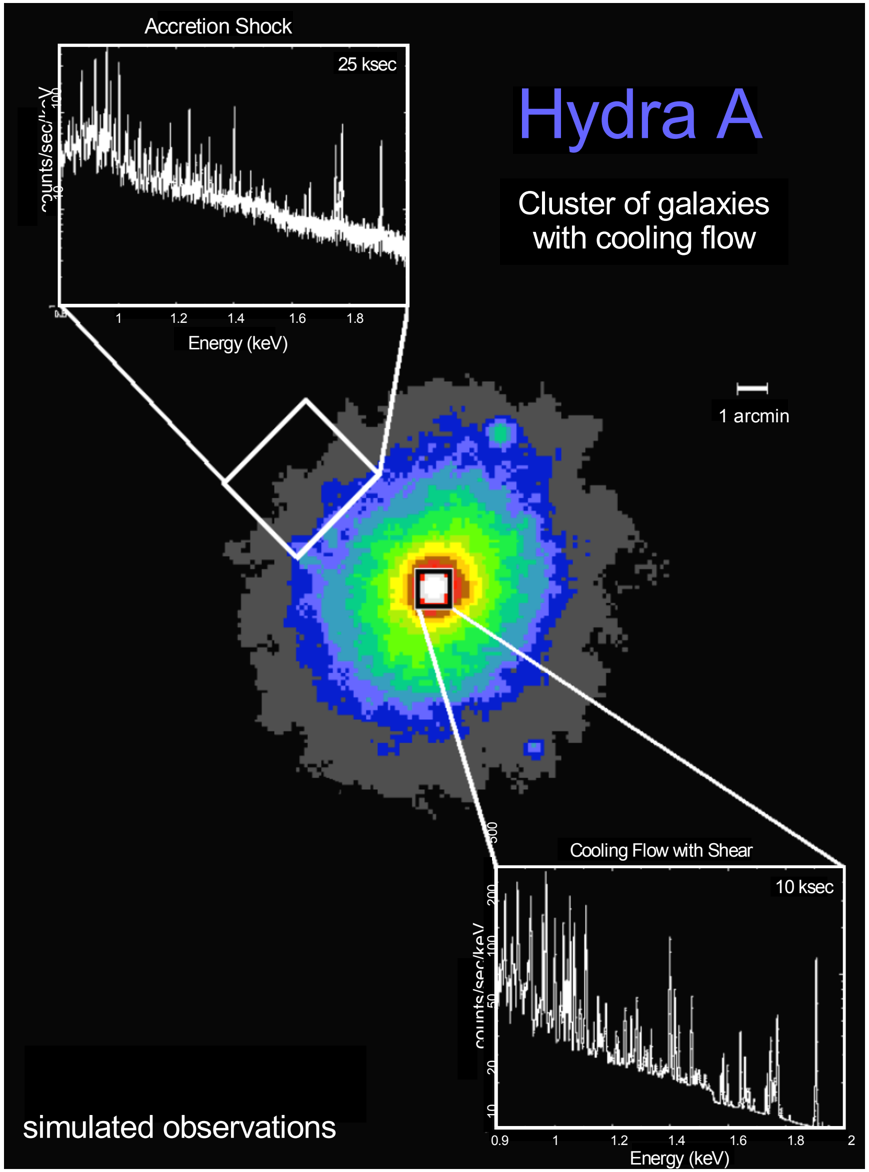
A 20 ks Constellation-X exposure of the NLSy1 galaxy IRAS 13224 with different cloud dispersion velocities for the absorbing medium.

- What is the composition and geometry of the accretion flow?
- How is material transported to the centers of AGN?



Emission features from an ionized absorbing medium.

When Were Clusters of Galaxies Formed and How Do They Evolve?

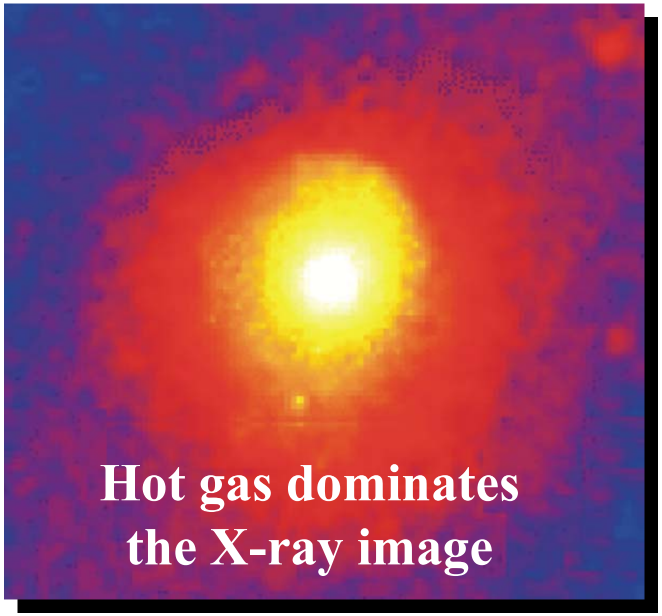


Clusters of galaxies provide a uniquely useful probe of Cosmology

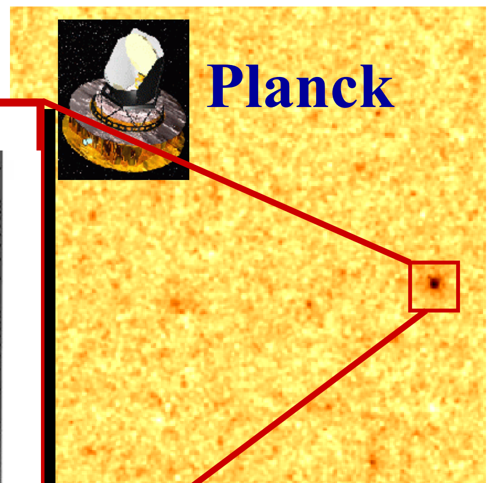
- Clusters are "simple" objects that are fair samples of the universe - they reflect the underlying dark matter to baryon ratio
- The abundance and redshift distribution of clusters determine the geometry of the universe
- Merging clusters can be used to test dark matter models
- Cluster elemental abundance measurements provide a powerful "dust free" measure of the star formation history of the Universe

Constellation-X observations of clusters of galaxies are essential to understand structure, evolution, and mass content of the Universe

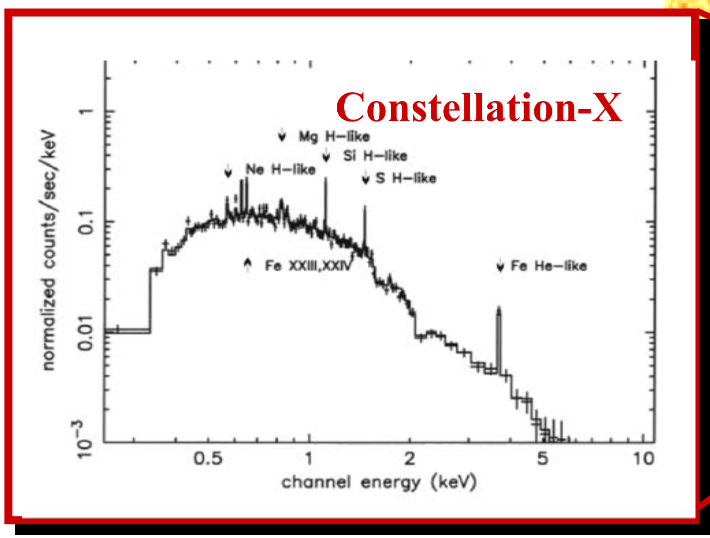
Cosmology with Clusters of Galaxies



- **Clusters of galaxies are the largest & most massive objects known**
  - The matter we "see" is dominated by hot gas
  - Dark matter makes up 90% of the total mass!
- **Precise determination of Cosmological parameters by measuring the abundance of clusters with redshift**



Planck and other microwave background surveys will find clusters at all redshifts



Precision spectroscopy by Constellation-X of faintest, most distant clusters will determine redshift and cluster mass to constrain Cosmological models & parameters

The Missing Hydrogen Mystery

An inventory of the visible matter in today's Universe gives only 20% of the baryons (mostly Hydrogen) found at high redshift in the Lyman-a forest

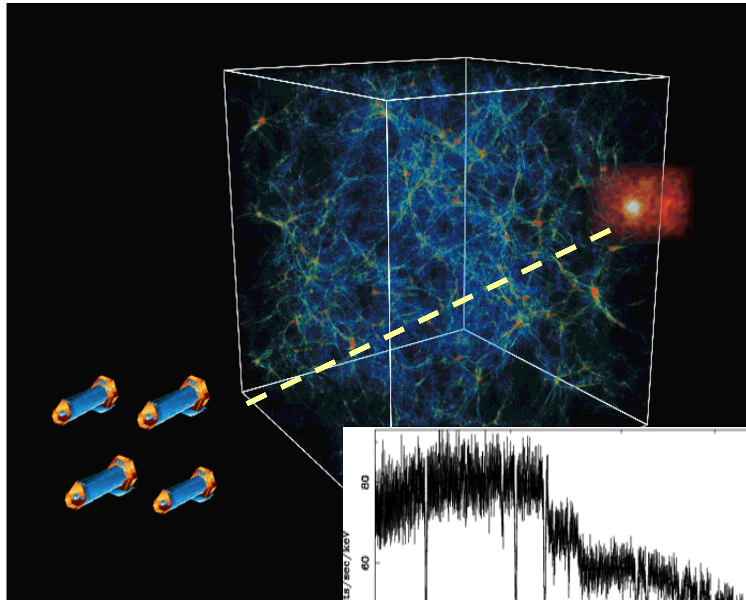
– Models for the formation of structure under the gravitational pull of dark matter predict the "unseen" baryons are in a 0.1 to 1 million degree K intergalactic gas, that had not been detected

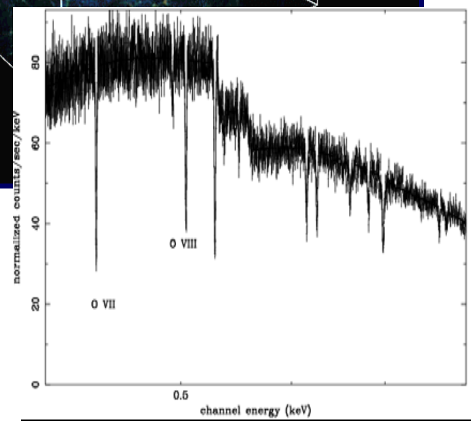
HST revealed ~15% of these predicted baryons using UV OVI absorption lines seen against bright background Quasars

- most sensitive to 0.1 million degree gas

Constellation-X will search for the remainder and can detect up to ~70% using O VII and O VIII absorption lines

- most sensitive to 1 million degree gas

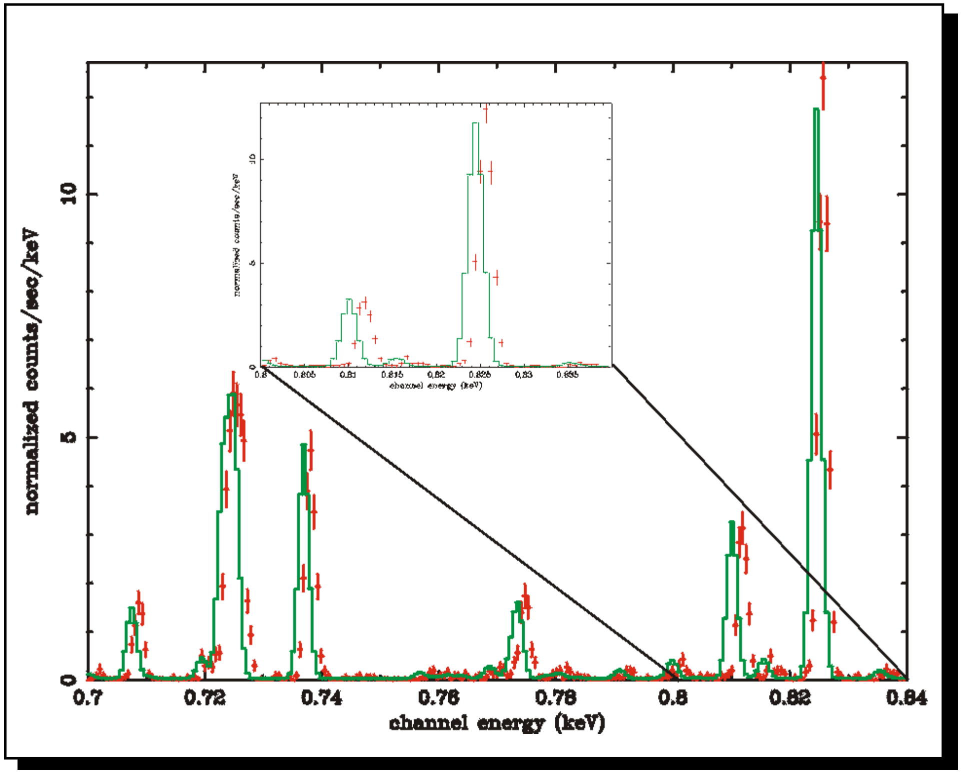




Together, UV and X-ray observations completely constrain the problem

Dark Matter Distribution in Spiral Galaxies

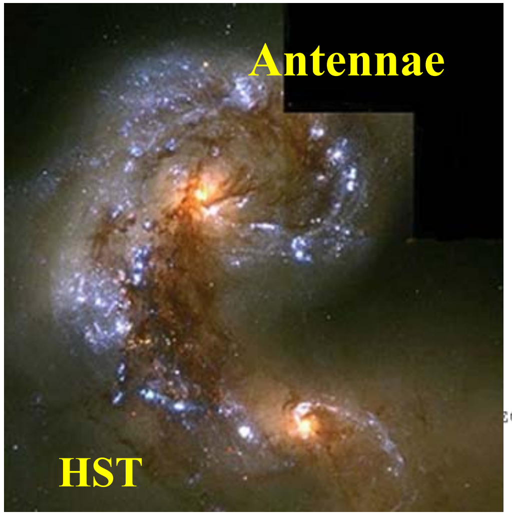
- Rotation curves of cold gas and stars prove existence of dark matter halos. Since stars and gas are confined to the plane of the galaxy, the rotation curves probe only 2D distribution of dark matter
- By measuring the T and r distribution of hot gas surrounding the galaxy, as well as its rotational velocity, the 3D distribution of dark and luminous matter in the galaxy can be determined
- Expected rotation velocities are ~ 300 km s^{-1} - well within Constellation-X capabilities

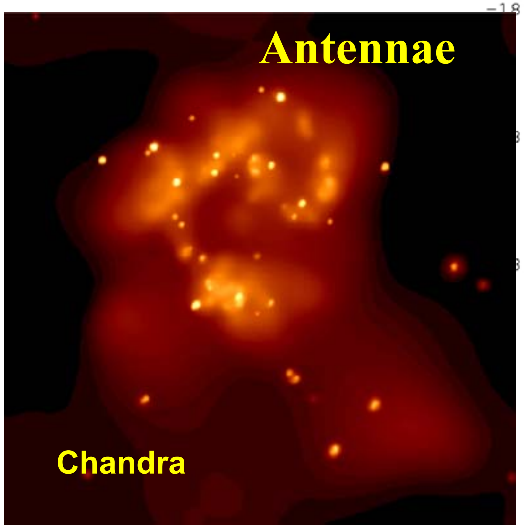


A 50 ks simulated observation of the hot halo gas in the edge-on spiral galaxy NGC 891. The solid line shows 0.3 keV gas model shifted by 600 km/s (assuming halo circular velocity of 300 km/s based on disk measurements).

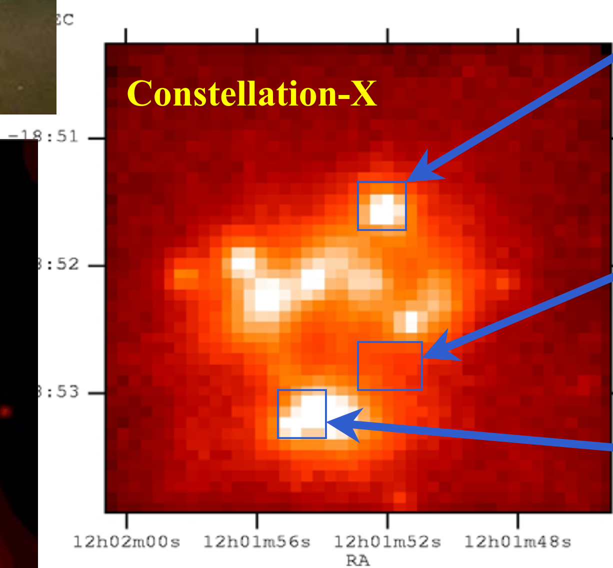
Credit: Diana Worrall

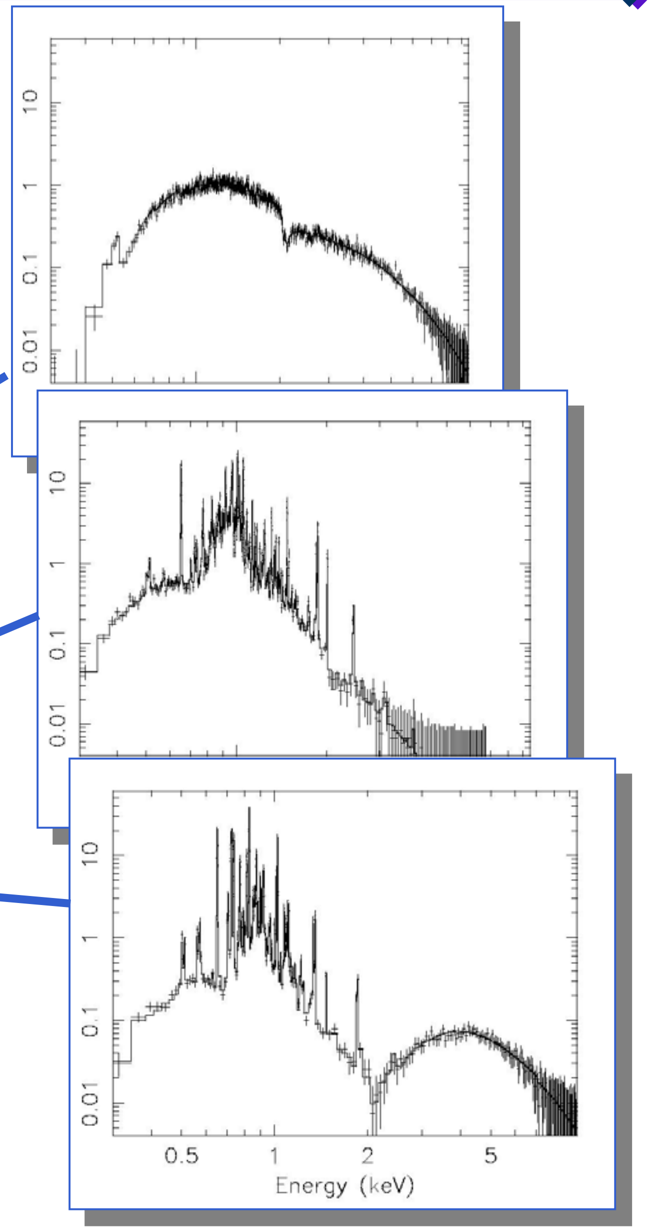
Hot ISM in Spiral Galaxies: The Antennae





Constellation-X needed to map the hot IGM in the Antennae to determine the plasma parameters (density, abundance, velocities, ionization state) of the hot ISM

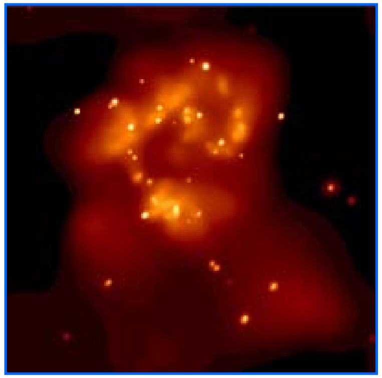


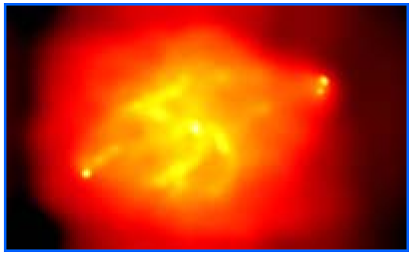


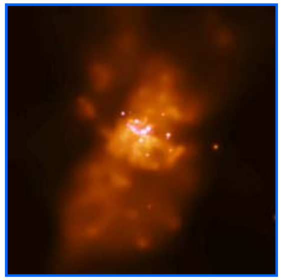
Constellation-X will compliment Chandra by giving 900 high resolution spectra across the galaxy in one observation

Credit:Kim Weaver/Steve Snowden

X-ray Roadmap to the First Galaxies





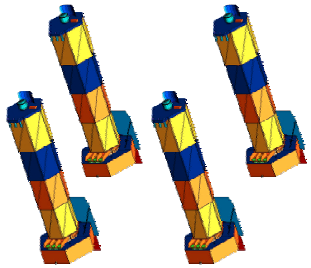


Chandra

0.1 m²

0.5 arc sec

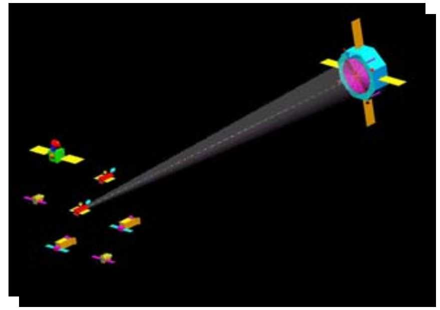
Constellation-X



3 m²

5-15 arc sec

Generation-X



150 m²

0.1-0.5 arc sec

Morphology of nearby galaxies

Dynamics and plasma diagnostics of hot inter-galactic medium in nearby galaxies

Formation of the first galaxies & black holes

Constellation-X Top Level Schedule

Schedule designed to establish continuity and overlap with Chandra & XMM-Newton

Activities and future plans:

- Mission in formulation since 1997
- In NASA strategic plan for new start before 2007
- Technology program well underway
- Instrument AO and selection between 2003 to 2005
- Mission implementation (C/D) start between 2006 to 2007
- First Launch between 2009 and 2010, with second launch one year later

McKee-Taylor Survey Highlights Constellation-X

The Constellation-X mission received strong endorsement from the influential McKee-Taylor National Academy of Sciences Astronomy and Astrophysics 2000-2010 decadal survey

From the report:

“Constellation-X Observatory is the premier instrument to probe the formation and evolution of black holes... the first clusters of galaxies... quasars at high redshift... and the formation of the chemical elements…”

“Constellation-X will compliment Chandra, much as Keck and Gemini compliment HST…”

“it has been under study for 5 years and the technology issues are well in hand for a start in the middle of the decade”

Constellation-X Summary

The Constellation-X science program will make high resolution X-ray spectroscopy routine to study:

- Black holes: strong gravity & evolution
- Evolution of large scale structure in the Universe
- Production and recycling of the elements

Technology and mission design well underway

- Assembly line production
- Multi-satellite concept reduces risk
- First launch in 2009 to 2010 timeframe

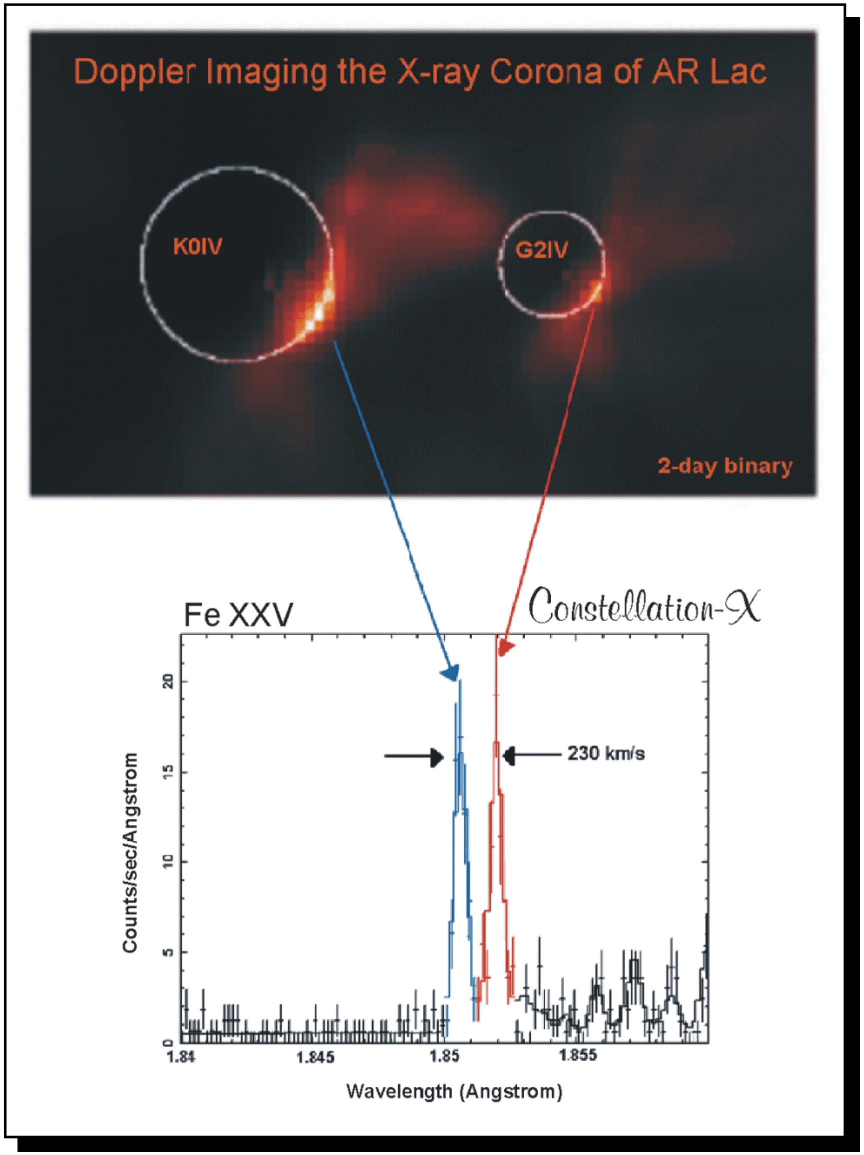
Facilitates ongoing science-driven, technology-enabled extensions

- Lightweight X-ray optics
- Energy bandwidth
- High spectral resolution

http://constellation.gsfc.nasa.gov

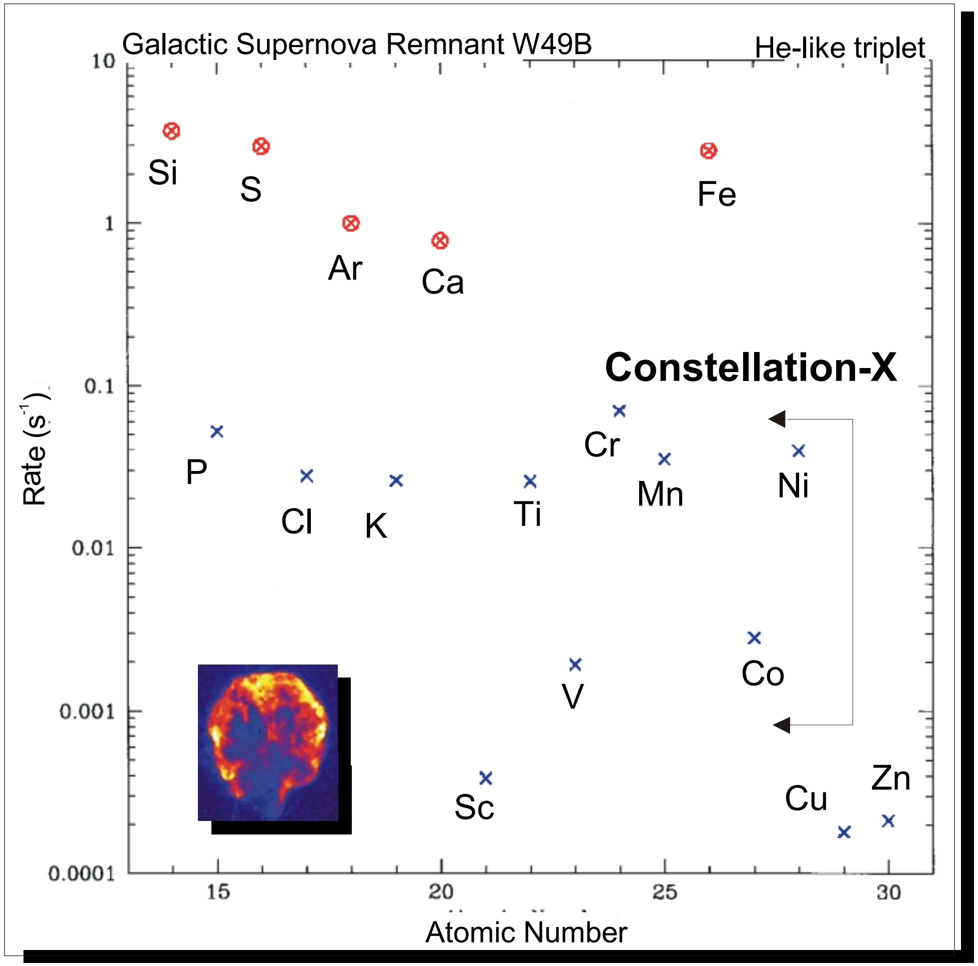
Back up charts

Constellation-X Observations of Stellar Coronae



- Plasma spectroscopy and Doppler imaging of coronal activity in stars
- Study magnetic reconnection, mass motion, densities, and abundances in stellar flares
- Investigate the formation and evolution of magnetic dynamos in young and pre-main sequence stars in molecular clouds
- Obtain high resolution spectra of stellar coronae from a wide range of luminosity
- Obtain high quality spectra of active stars such as RS CVn and Algol systems out to ~30 kpc

Constellation-X Measurements of Chemical Enrichment in SNRs



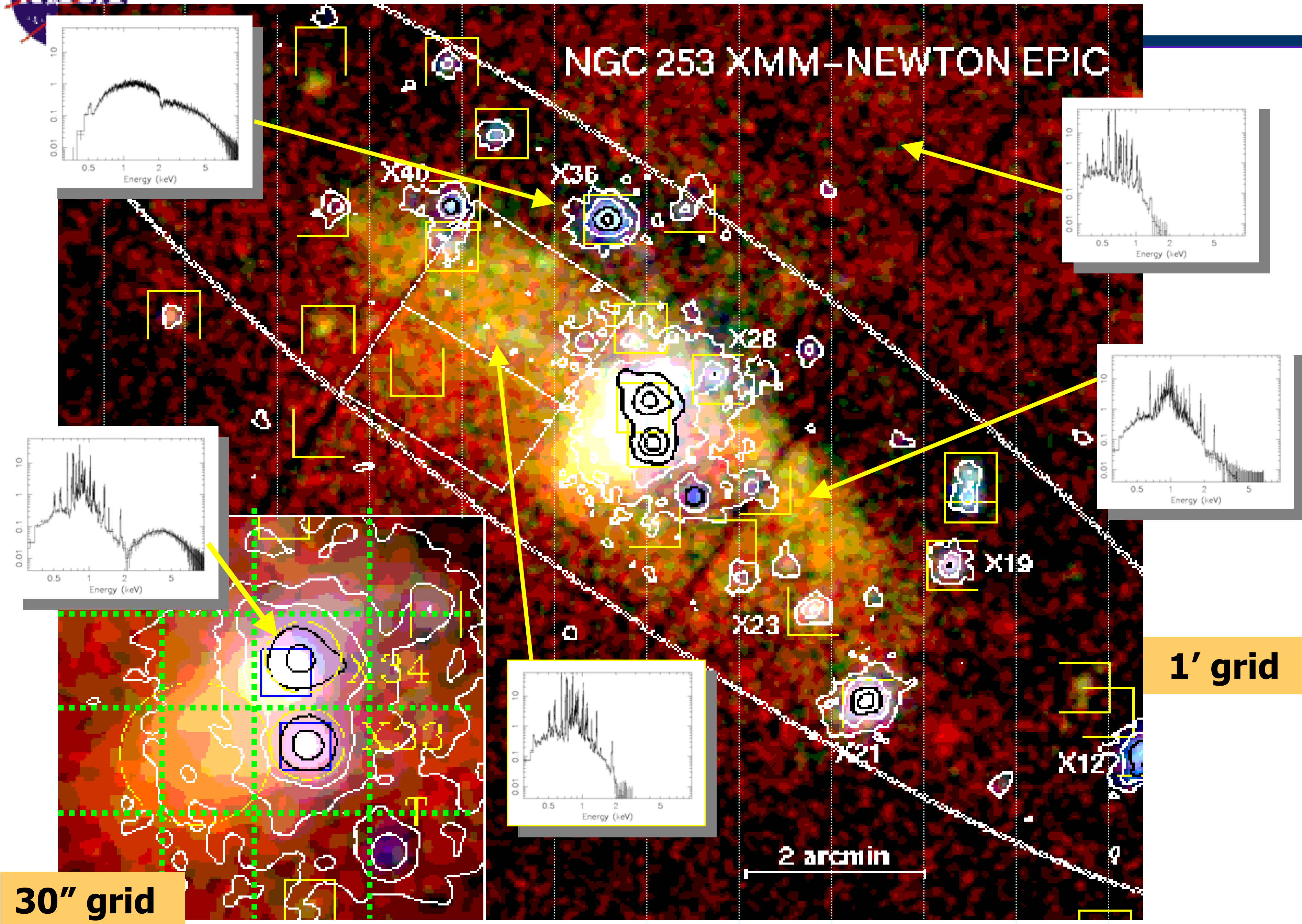
Determine the abundance and velocity distribution of even- and odd-Z elements from Carbon to Zinc in extended supernova remnants

Significant detection of odd-Z elements achieved by Constellation-X in less than 20 ks will investigate the processes that lead to their production (beyond the α-processes)

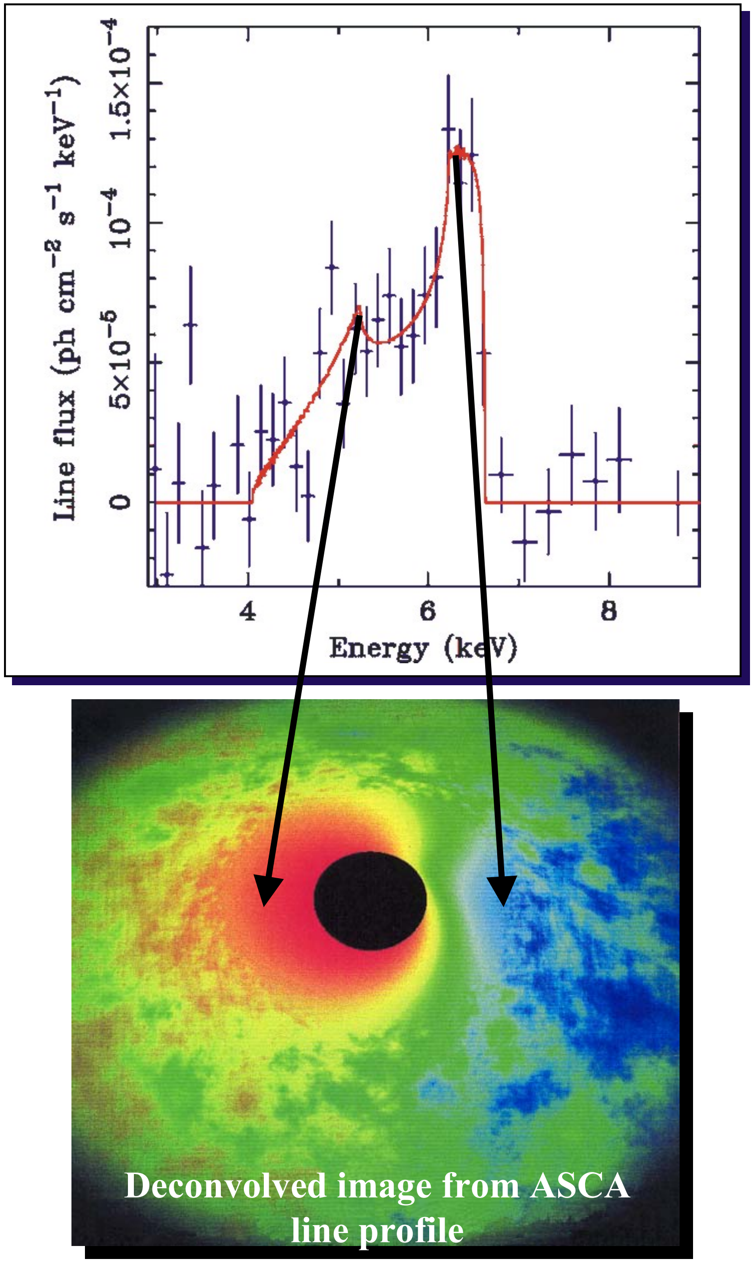
Search for non-thermal components using the HXT to constrain Cosmic Ray models

Credit: Jack Hughes

Spatially-resolved Spectroscopy



Indirect Imaging of Black Holes Using Spectroscopic De-convolution

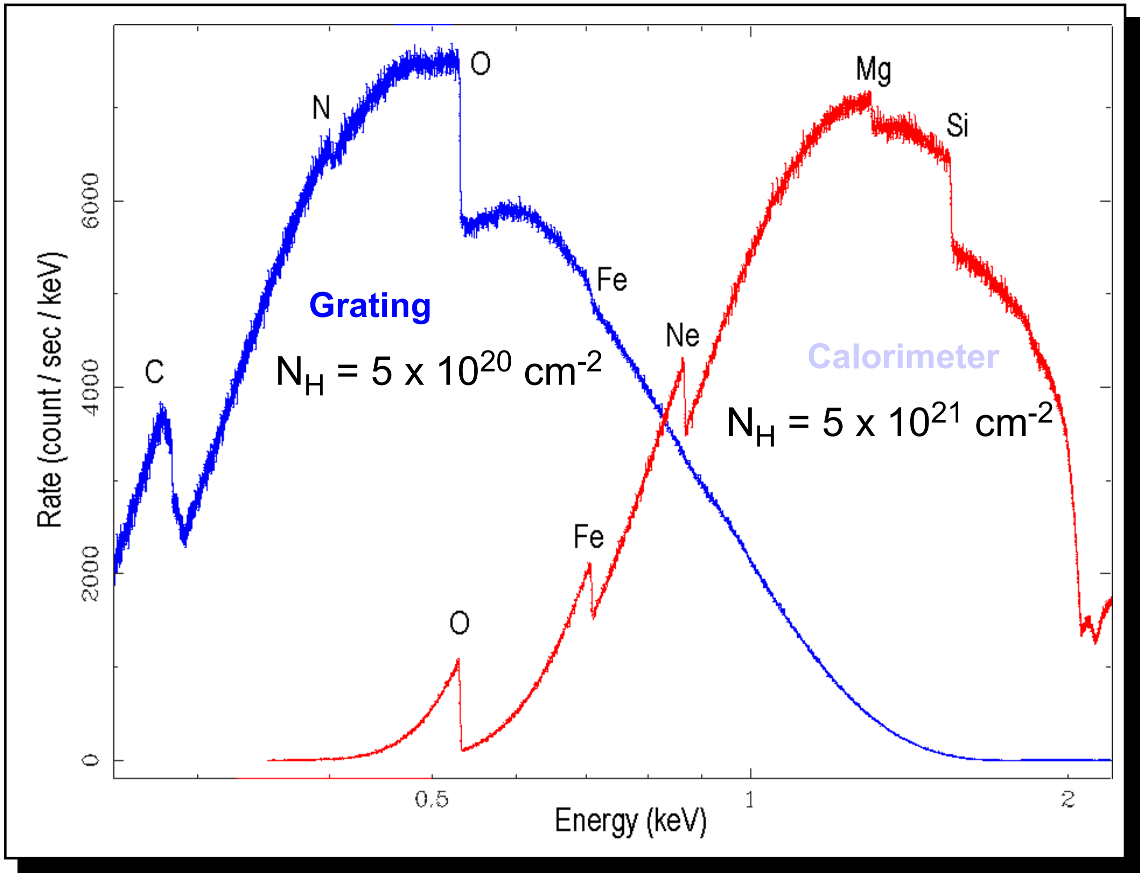


Deconvolved image from ASCA line profile

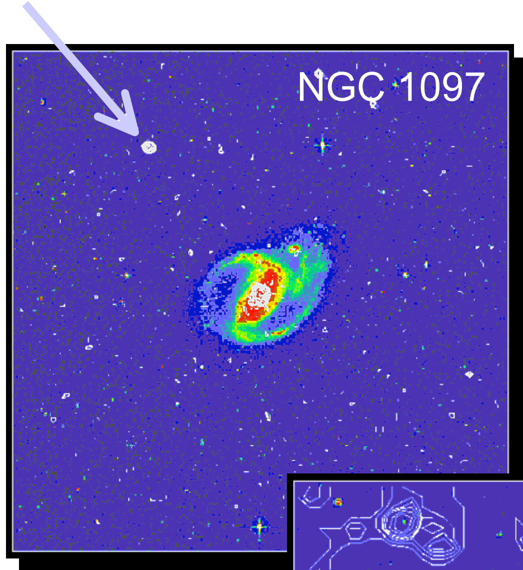
- **ASCA discovered a relativistically broadened iron line that come from close to the event horizon of black holes in the nucleus of nearby galaxies**
- **This line provides a unique probe of the inner sanctum near black holes, observing the effects of GR in the strong gravity limit**
- **Much larger collecting area and improved energy resolution required to exploit this diagnostic**
  - **Constellation-X is designed for this**

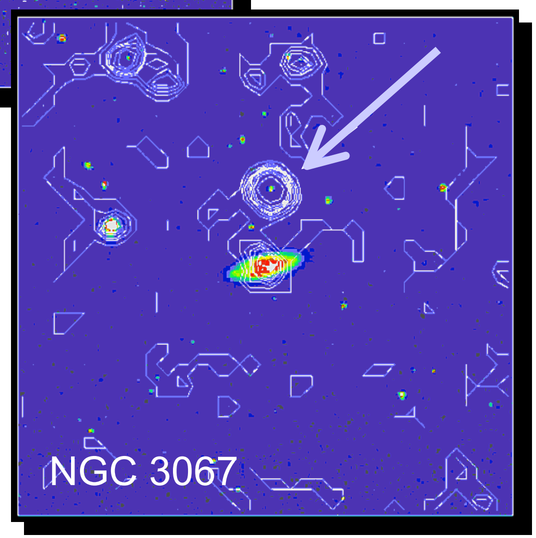
Galactic Halos

The composition and state of the tenuous hot halos of Galaxies can be accurately measured via K or L shell absorption of X-rays against background quasars



Spectra of two typical quasars absorbed through two different hydrogen column densities in the ISM





There are more than 300 bright X-ray galaxies for which such measurements can be made

Constellation-X Extendible Design